IV.

CONTRIBUTIONS FROM THE PHYSICAL LABORATORY OF HARVARD COLLEGE.

XXV. — ATMOSPHERIC ELECTRICITY AT HIGH ALTITUDES.

By Alexander McAdie, M.A.

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The following experiments were made at Blue Hill Observatory during the month of June, 1885. The summit of the Hill has an elevation of 635 feet above sea level, and is therefore the highest point on this section of the Atlantic seaboard. With the exception of the two or three other hills in the range, all the surrounding country is very low and level. The average elevation is below 100 feet. On all sides this low land is well watered, having rivers of fair size and many ponds. For these reasons it was thought profitable to make some observations on the electrical state of the atmosphere, similar in nature to a series made for the United States Signal Service at the Jefferson Physical Laboratory in Cambridge.

The following apparatus was taken to the summit, and employed as hereafter described: —

A Multiple Quadrant Electrometer, designed by Professor Trowbridge, a description of which may be found in the Proceedings of the American Academy, June, 1885.

A portable battery of 100 Beetz cells, set up in series.

A second battery of the same kind, the cells arranged for convenience in sets of ten.

A newly set up Daniell cell.

Two large light kites, silk-covered and tinfoiled on the front face; the longest axes of the kites being over 4 feet.

1,500 feet of strong hemp fish-line, around which in a close spiral was wound No. 22 uncovered copper wire.

50 feet of insulated office wire, and some 10 or 12 feet of rubber tubing, to better insulate the office wire.

One electrometer commutator, and some binding screws.

A condenser, with a capacity of $\frac{1}{3}$ farad, was also brought up, but when required for use was found to be defective and of no value.

The first observations were made on June 17, at nine A. M.

The first step was to measure the difference between the potential of the air, at a point a few feet out from the observatory walls and about five feet above the ground, and the ground potential. Instead of using the insulated water-dropper devised by Sir William Thomson, I made use of the method employed with success at Cambridge; namely, of dropping water on an insulated metallic plate, and allowing it to fall in drops therefrom. Making the electrometer connections in the way adopted by Thomson and English writers generally, — that is, connecting one set of quadrants with the insulated plate, the other set with the ground, and bringing the needle to a high potential by connecting with the plus pole of a battery of high electromotive force, — the electrometer indicated no appreciable difference between the potential of the air at that point and the potential of the ground. The ground, it may be remarked, was not at the observatory itself, — for the summit is a ledge of solid rock, — but a telephone ground, made of a wire running down the hillside some distance, and connected at different places with metallic plates buried in the earth.

Using the method adopted by Mascart in making the electrometer connections, — that is, connecting one set of quadrants to the plus pole of the 100-cell battery, and the other set of quadrants to the negative pole of the same battery, while the needle is connected with the insulated plate or body whose potential is to be determined, — no appreciable deflection due to the difference between the potentials of the air and ground could be noticed. The insulated plate has to be disconnected, and in its stead the ground substituted in order to ascertain this difference of potential. The electrometer is designed to measure only where differences of potential exist that are of considerable value. The needle of the electrometer carries a fine aluminium pointer, allowing one to read the deflections directly.

In the mean while, the kite having been raised to an elevation of 200 feet, the wired kite-string was now connected with one set of quadrants, and the other set connected with the ground. The needle was connected with the plus pole of the 100-cell Beetz battery, the other pole being grounded. Great care was taken to insulate very thoroughly the kite-string, as with electricity of high tension ordinary methods of insulation are not sufficient. Instantly on making connection, the needle was deflected with a considerable impulse beyond the

limit of the scale (25 scale divisions), and until stopped by the side of the case of the instrument. The deflection indicated a very high positive potential for the air in the vicinity of the kite. To decrease the sensibility of the instrument, the battery charging the needle was reduced from 100 cells to 10 cells, and finally to a single cell. The Beetz battery of 100 cells has a difference of potential between its plus and minus poles of about 100 volts. The needle-pointer being at 0, the plus pole of the battery being connected to one set of quadrants, caused a deflection of 5.5 scale divisions. Connecting the insulated kite-string to the same terminal, the aluminium pointer was deflected with force to the side of the case. The least value of the difference between the kite potential and the ground was about 500 volts. The wind at this time was blowing freshly from the northwest, and the kite was seemingly stationary. Touching the ground wire, for a second, to the kite wire, a small spark about one twentieth of an inch in length was obtained. This, of course, discharged the wire, and the pointer returned to 0, returning, however, almost at once, again to the side of the case. In the hope of getting the deflection within the limits of the scale of the instrument, the quadrants connected with the ground were instead connected with the plus pole of the 100-cell Beetz battery. The deflection under this arrangement would represent the excess value of the air potential over that of the battery terminal. The deflection, however, still remained off the scale, though evidently not very distant. This deflection was maintained all the forenoon. The sky was covered with a low pallium of dark stratus clouds, and the weather was generally muggy and threatening. At three P. M. the kite was sent up as before. The same character of deflection prevailed, and the sparks obtained on connecting the ground with the kite wire were larger and as frequent as in the morning. The shock felt on touching these two wires with the fingers slightly moistened was about the same as one gets from a small-sized Leyden jar. The weather had cleared up, and it was now a clear and pleasant June afternoon. The wind was less steady than in the morning, coming more in puffs. In consequence of this, the kite was less steady, and kept rising and falling. Every time, without exception, when the kite would rise, the needle indicated an increase in the potential; and, on the other hand, as regularly as the kite fell the deflection decreased. When the kite would get apparently within 100 feet of the ground, the deflection would often fall to 8, 10, and sometimes less, of the scale divisions. The movements of the kite were told from watching the movements

of the needle, and about as quickly as they could be seen from without.

On June 18, at 2 h. 30 m., P. M., these experiments were repeated. As before, no difference could be detected between the potential of the air a few feet from the ground, and that of the ground. It is to be remembered, however, that in the present adjustment of the electrometer, a difference equivalent to two volts was the minimum difference that could be detected. With the same instrument, adjusted for greater sensitiveness, employing the same methods, I have found in another locality a difference equivalent to a volt and more between a point in air 10 feet from the ground and the ground itself. The sky had been perfectly cloudless for many hours, and was now without clouds, except one or two very small rounded cumuli in the east. These also in the course of an hour disappeared, and the sky was again cloudless. The height of the kite was determined experimentally, by sending up a carrier on the kite-string, to which was attached thread, with markers at certain distances, made of folded wrapping paper, and of just sufficient weight to keep the thread perpendicular. The distance between the last marker and a level line of sight from the summit was estimated, and added to the known length of thread. My own carrier device having failed, Mr. Willard Gerrish, of the Observatory, suggested a conical-shaped carrier, which answered well. When the kite was about 350 feet high, the needle was deflected off the scale, but did not press against the side of the case of the instrument. When the kite was about 200 feet high, the deflections were in the neighborhood of 10, and variable in character. At this time, then, it was easily possible to notice and record the fluctuations in the value of the potential of the air. At times the needle would start suddenly and swing off the scale; sometimes remaining off, sometimes immediately returning. At other times it would fall to 5, 7, or 8, and either remain at these figures for a while, or vary greatly therefrom.

At 4 h. 30 m., with a cloudless sky, the kite being at a height of 300 feet, the deflection was 23+. The kite was then pulled down until only about half as high as before, and the average deflection was 15+. At 4 h. 50 m., the kite being about 400 feet high, the length of kite-string being about 700 feet, and the distance between the kite and the ground beneath it about 1,000 feet, there being a deep glen between this and the next hill, the deflection was off the scale, and apparently much greater than when at 300 feet. The sparks obtained by presenting the ground-wire to the kite-wire were larger than before,

being about one eighth of an inch in length. The sky was perfectly cloudless at this time. As the kite remained very steady, it was fastened, and allowed to remain up until near eleven o'clock. The deflection of the needle was observed at frequent intervals, and the needle then brought back to the zero by connecting with the ground.

At eight P. M. the kite was more to the northeast than before, but at about the same elevation. The deflections, however, were much less than during the rest of the day, and for the most part within the scale limits. The needle kept constantly moving, but with little of the vigor it had previously shown. The character of the deflections may be illustrated by the following record for a single minute: —

Time. June 19. 1885, P. M. h. m. s.	Deflection.	Character.	Equivalent in Volts to
8 4 0	24+	Steady.	Over 500
10	10	Variable.	" 200
20	8	Decreasing steadily.	" 150
30	15	Very variable.	" 300
40	15	Variable, increasing and decreasing.	" 300
50	8 to 15	Variable.	" 150
8 5 0	10		" 200

The movements of the kite at this time appeared to be very slight, and one would be apt to suppose too small to account for the great potential changes. But it must be noticed that the movements of the kite, as far as they could be made out, were always in the proper direction to correspond with the character of the potential changes; that is, a rise in the position of the kite was attended with an increasing potential, and a fall attended with a decreasing potential.

At 8 h. 20 m. the deflection was very steady in character, and about 18. The potential indicated by that deflection was not sufficient to give a spark. Fifteen minutes later fair-sized sparks could be obtained at very short intervals. At nine o'clock the same condition prevailed. At ten o'clock the sparks were larger and more frequent. The sky during the whole time was cloudless.

The morning of June 19 was cloudless but hazy, and there was not sufficient wind to fly the kite. In the late afternoon, the wind having freshened from the southwest, the kite was raised to an elevation of about 500 feet above the summit. The kite remaining steady, the deflection was beyond the range of the instrument, and evidently greater than had yet been obtained. Large sparks could be obtained every few seconds by presenting the ground-wire to the kite-wire.

The observatory at Blue Hill is provided with a self-registering anemoscope and a self-registering anemometer. It was originally intended to get a record of the potential variations, and compare it with the records of these two instruments. Unfortunately, both had to be returned to the maker for alterations, because of changes made in the building. It also became apparent that some form of self-recording electrometer was needed. I believe that by means of self-recording instruments the subject of atmospheric electricity can be most advantageously studied. The main purpose in these experiments was to show that it is possible to get some knowledge of the electrical condition of the air at a distance from the ground, with the imperfect means now at our command.

The one point of striking interest in these experiments is the obtaining evidence of this high electrical potential in a sky free from clouds. It will perhaps afford an argument against the necessity of considering condensation in explaining the origin of atmospheric electricity.

It may still be questioned whether these experiments prove that the potential of the air is positive, and increases steadily with increase in elevation. The effects observed may possibly be due to the friction of the air against the tinfoiled kite. My own opinion inclines to the former belief. Questions of this nature, however, can be definitely settled by the results of many and long observations. To accomplish these it is indispensable that a self-recording electrometer be devised, so that the records obtained may be directly comparable with the continuous records of the more prominent meteorological conditions.

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CAMBRIDGE, MASS.